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MINIMUF-3.5
Improved version of MINIMUF-3, a simplified hf MUF prediction algorithm

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MINIMUF
Minimum usable frequency
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Within an 800-8000 km range, the original MINIMUF-3 reported in NOSC TR 186 will predict hf MUF within specified confidence limits. But the development of new applications involving very long transmission paths uncovered several bugs. Corrections are reported here that do not affect the original accuracy limits but do allow MINIMUF to be used out to the antipodal point. This document presents the most current model, called MINIMUF-3.5, describes the improvements, and presents a data set with which each user can check out his version of MINIMUF-3.5.

INTRODUCTION

The initial report on the MINIMUF-3 model (ref 1) found widespread interest throughout the hf community. That model has been successfully adapted for use on a variety of minicomputers and microcomputers and has been used in numerous ways. As long as the 800–8000 km range constraint discussed in ref 1 is not exceeded, the original MINIMUF-3 will perform within confidence limits specified in the first verification study. But the development of new applications involving very long transmission paths uncovered several bugs that had to be corrected. The changes made do not affect the original accuracy limits but do allow MINIMUF to be used out to the antipodal point. The purposes of this document are to present the most current model, called MINIMUF-3.5, to describe the improvements made, and to present a data set with which each user can check out his version of MINIMUF-3.5. The original report, ref 1, explains the theory behind this model.

CHANGES TO ORIGINAL MINIMUF MODEL

The model listed in the BASIC program on page 41 of reference 1 contained two problems, as follows.

1. Line number 891 is a conditional branch:

```
891 IF COS(LØ+Y2)>-Ø.26 THEN 9ØØ
```

If the branch to line 900 is not taken, subsequent execution of the line

```
122Ø G2=G2*(1-Ø.1*EXP((K9-24)/3))
```

references the variable K9, which will not have been properly defined.

The problem is eliminated by insertion of the following line of code:

```
892  K9=Ø
```

2. For very long path lengths, the computed MUF is unrealistically low. For paths sufficiently long, a fatal error can occur at line 898 or line 1000 with a negative argument for the square root function. This is because the value of M9 (computed in line 897 or 990) reaches a maximum value for a path length of about 8000 km (the longest path used in the verification tests) and then decreases in magnitude, becoming negative for path lengths of about 16 000 km. The following changes correct this problem:

Delete lines 897, 898, 990 and 1000. Insert the lines

```
897 M9=SIN(2.5*G1*K5 MIN PI/2)
898 M9=1+2.5*M9*SQR(M9)
99Ø M9=SIN(2.5*G1*K5 MIN PI/2)
1ØØØ M9=1+2.5*M9*SQR(M9)
```

In addition to these changes, MINIMUF-3.5 uses a somewhat different solution for the spherical trigonometry problems involved in computing path length and control point coordinates. This change simplifies the code and eliminates the need for GOSUBs to external subroutines. It affects neither the solution obtained nor the computed value of MUF.

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[1] NOSC TR 186, MINIMUF-3: A Simplified Hf MUF Prediction Algorithm, by RB Rose, JN Martin, and PH Levine, 1 February 1978

REVISED MINIMUF BASIC PROGRAM

A listing of the MINIMUF-3.5 program is included. Lines 100 through 720 contain a small driver which allows the model to be exercised. The actual MINIMUF program starts at line 1000.

The input variables for the MINIMUF program are as follows:

L1	– Transmitter latitude, radians ($-\pi/2 \leqslant L1 \leqslant \pi/2$)
W1	– Transmitter west longitude, radians ($-2\pi \leqslant W1 \leqslant 2\pi$)
L2	– Receiver latitude, radians ($-\pi/2 \leqslant L2 \leqslant \pi/2$)
W2	– Receiver west longitude, radians ($-2\pi \leqslant W2 \leqslant 2\pi$)
MØ	– Month ($1 \leqslant MØ \leqslant 12$)
D6	– Day ($1 \leqslant D6 \leqslant 31$)
T5	– Time (UT), hours ($Ø.Ø \leqslant T5 \leqslant 24.0$)
J9	– Output MUF, MHz
S9	– Sunspot number
PI	– 3.141593
PØ	– 1.570796

In using the test driver program, transmitter and receiver coordinates should be input in degrees; the driver converts these to radians as required by the MINIMUF subroutine.

Figure 1 is a sample output listing that users may find helpful in getting their version of MINIMUF to work.

```
TRANSMITTER LAT, LON = 21,156
RECEIVER LAT, LON = 38,122
DATE (DAY,MONTH) = 17,10
SUNSPOT NUMBER = 100

        DATE: 17 OCT
        TRANSMITTER LOCATION:   LATITUDE 21.00, LONGITUDE 156.00
        RECEIVER LOCATION:      LATITUDE 38.00, LONGITUDE 122.00
        SUNSPOT NUMBER = 110

           HOUR        MUF(MHZ)

             0           32.0
             1           32.0
             2           32.0
             3           29.9
             4           25.0
             5           22.0
             6           20.9
             7           19.3
             8           18.0
             9           16.9
            10           16.0
            11           15.2
            12           14.6
            13           14.1
            14           13.7
            15           21.0
            16           27.6
            17           31.5
            18           32.0
            19           32.0
            20           32.0
            21           32.0
            22           32.0
            23           32.0

        PRESS RETURN TO PERFORM NEXT CASE.
```

Figure 1. Example of a 24-hour MUF listing of MINIMUF-3.5.

APPLICATION TIPS

With increasing solar activity, user interest in updating MINIMUF to reflect current solar activity has also increased. The updating method found to be most effective was to vary the sunspot number input parameter as a function of 107 mm solar radio flux. Because of the lag in F-region response to a rapid increase in solar activity, it is best to use either a 5-day, 15-day or 90-day running mean average of the 107 mm flux. The type of application will determine which is best. The 5-day mean is a shorter-term more dynamic input, while the 90-day mean is more applicable for long-term planning. These flux values can be acquired from

Space Environment Services Center, Boulder, Colorado

WWV transmissions at 18 minutes after each hour.

The conversion from 107 mm flux to sunspot number is accomplished by the graph shown as figure 2.

Two other points are borne out by field testing. First, MINIMUF is an F-region approximation. Any intervention by E-region modes of propagation, either as multiple E or EF complex modes, is not predictable on MINIMUF. Such operational situations, however, are proving to represent only a small percentage of the total. Second, MINIMUF has the greatest accuracy within the one- and two-hop ranges, between about 800 and 8000 km. Predictions for transmission paths longer than this should be used with some caution.

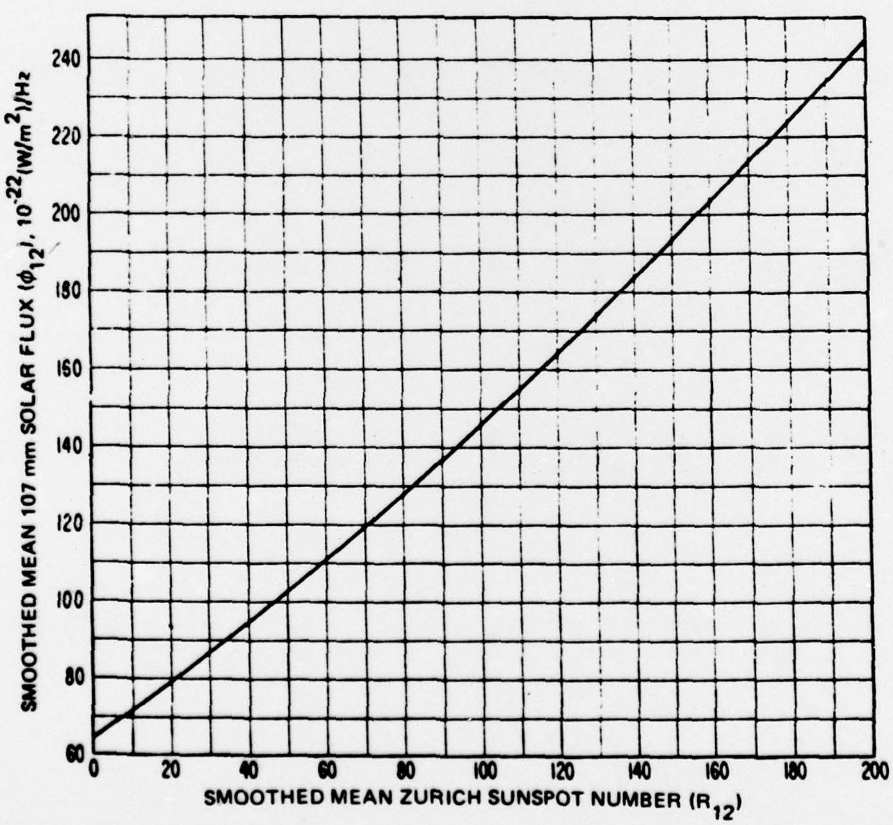

Figure 2. Relationship between smoothed mean Zurich sunspot number and smoothed mean 107 mm solar flux.

TEST DRIVER PROGRAM

```
100 INIT
110 DIM M$(37),A$(4),M(12)
120 DATA 31,28,31,30,31,30,31,31,30,31,30,31
130 READ M
140 M$="JANFEBMARAPRMAYJUNJULAUGSEPOCTNOVDEC"
150 R0=PI/180
155 P1=2*PI
160 R1=180/PI
170 P0=PI/2
180 PAGE
190 PRINT "TRANSMITTER LAT, LON = ";
200 INPUT L1,W1
210 IF -90<=L1 AND L1<=90 THEN 240
220 PRINT "INVALID LATITUDE.  MUST BE IN RANGE (-90,+90)."
230 GO TO 190
240 IF -360<=W1 AND W1<=360 THEN 270
250 PRINT "INVALID LONGITUDE.  MUST BE IN RANGE (-360,+360)"
260 GO TO 190
270 PRINT "RECEIVER LAT, LON = ";
280 INPUT L2,W2
290 IF -90<=L2 AND L2<=90 THEN 320
300 PRINT "INVALID LATITUDE.  MUST BE IN RANGE (-90,+90)."
310 GO TO 270
320 IF -360<=W2 AND W2<=360 THEN 350
330 PRINT "INVALID LONGITUDE.  MUST BE IN RANGE (-360,+360)."
340 GO TO 270
350 PRINT "DATE (DAY,MONTH) = ";
360 INPUT D6,M0
370 IF 1<=M0 AND M0<=12 THEN 400
380 PRINT "INVALID MONTH.  MUST BE IN RANGE (1,12)."
390 GO TO 350
400 IF 1<=D6 AND D6<=M(M0) THEN 430
410 PRINT USING 420:M(M0)
420 IMAGE "INVALID DAY.  MUST BE IN RANGE (1,",FD,")."
425 GO TO 350
430 PRINT "SUNSPOT NUMBER = ";
440 INPUT S9
450 IF S9>0 THEN 480
460 PRINT "INVALID SUNSPOT NUMBER.  MUST BE NON-NEGATIVE."
470 GO TO 430
480 PAGE
490 A$=SEG(M$,3*M0-2,3)
500 PRINT USING """DATE: "",FD,1X,FA":D6,A$
510 PRINT "TRANSMITTER LOCATION:  ";
520 PRINT USING 530:L1,W1
530 IMAGE "LATITUDE ",FD.2D,", LONGITUDE ",FD.2D
540 PRINT "RECEIVER LOCATION:     ";
550 PRINT USING 530:L2,W2
560 PRINT USING """SUNSPOT NUMBER = "",FD":S9
570 PRINT
580 PRINT "   HOUR     MUF(MHZ)"
590 PRINT
600 L1=L1*R0
610 W1=W1*R0
620 L2=L2*R0
630 W2=W2*R0
640 FOR T5=0 TO 23
650 GOSUB 1000
660 PRINT USING 670:T5,J9
670 IMAGE 5X,2D,7X,2D.D
680 NEXT T5
690 PRINT
700 PRINT "PRESS RETURN TO PERFORM NEXT CASE.";
710 INPUT A$
720 GO TO 180
```

MINIMUF-3.5 PROGRAM

```
1000 REM
1010 K7=SIN(L1)*SIN(L2)+COS(L1)*COS(L2)*COS(W2-W1)
1020 G1=ACS(K7 MAX -1+1.0E-5 MIN 1-1.0E-8)
1030 K6=1.59*G1
1040 K6=K6 MAX 1
1050 K5=1/K6
1060 J9=100
1070 FOR K1=1/(2*K6) TO 1-1/(2*K6) STEP 0.9999-1/K6
1080 IF K5=1 THEN 1100
1090 K5=0.5
1100 P=SIN(L2)
1110 Q=COS(L2)
1120 A=(SIN(L1)-P*COS(G1))/(Q*SIN(G1))
1130 B=G1*K1
1140 C=P*COS(B)+Q*SIN(B)*A
1150 D=(COS(B)-C*P)/(Q*SQR(1-C*C))
1160 D=ACS(D MAX -1+1.0E-5 MIN 1-1.0E-8)
1170 W0=W2+SGN(SIN(W1-W2))*D
1180 IF W0=>0 THEN 1200
1190 W0=W0+P1
1200 IF W0<P1 THEN 1220
1210 W0=W0-P1
1220 L0=P0-ACS(C MAX -1+1.0E-5 MIN 1-1.0E-8)
1230 Y1=0.0172*(10+(M0-1)*30.4+D6)
1240 Y2=0.409*COS(Y1)
1250 K8=3.82*W0+12+0.13*(SIN(Y1)+1.2*SIN(2*Y1))
1260 K8=K8-12*(1+SGN(K8-24))*SGN(ABS(K8-24))
1270 IF COS(L0+Y2)>-0.26 THEN 1350
1280 K9=0
1290 G0=0
1300 M9=2.5*G1*K5
1310 M9=M9 MIN P0
1320 M9=SIN(M9)
1330 M9=1+2.5*M9*SQR(M9)
1340 GO TO 1590
1350 K9=(-0.26+SIN(Y2)*SIN(L0))/(COS(Y2)*COS(L0)+1.0E-3)
1360 K9=12-ATN(K9/SQR(ABS(1-K9*K9)))*7.639437
1370 T=K8-K9/2+12*(1-SGN(K8-K9/2))*SGN(ABS(K8-K9/2))
1380 T4=K8+K9/2-12*(1+SGN(K8+K9/2-24))*SGN(ABS(K8+K9/2-24))
```

```
1390 C0=ABS(COS(L0+Y2))
1400 T9=9.7*C0↑9.6
1410 IF T9>0.1 THEN 1430
1420 T9=0.1
1430 M9=2.5*G1*K5
1440 M9=M9 MIN P0
1450 M9=SIN(M9)
1460 M9=1+2.5*M9*SQR(M9)
1470 IF T4<T THEN 1500
1480 IF (T5-T)*(T4-T5)>0 THEN 1510
1490 GO TO 1640
1500 IF (T5-T4)*(T-T5)>0 THEN 1640
1510 T6=T5+12*(1+SGN(T-T5))*SGN(ABS(T-T5))
1520 G9=PI*(T6-T)/K9
1530 G8=PI*T9/K9
1540 U=(T-T6)/T9
1550 G0=C0*(SIN(G9)+G8*(EXP(U)-COS(G9)))/(1+G8*G8)
1560 G7=C0*(G8*(EXP(-K9/T9)+1))*EXP((K9-24)/2)/(1+G8*G8)
1570 IF G0=>G7 THEN 1590
1580 G0=G7
1590 G2=(1+S9/250)*M9*SQR(6+58*SQR(G0))
1600 G2=G2*(1-0.1*EXP((K9-24)/3))
1610 G2=G2*(1+(1-SGN(L1)*SGN(L2))*0.1)
1620 G2=G2*(1-0.1*(1+SGN(ABS(SIN(L0))-COS(L0))))
1630 GO TO 1700
1640 T6=T5+12*(1+SGN(T4-T5))*SGN(ABS(T4-T5))
1650 G8=PI*T9/K9
1660 U=(T4-T6)/2
1670 U1=-K9/T9
1680 G0=C0*(G8*(EXP(U1)+1))*EXP(U)/(1+G8*G8)
1690 GO TO 1590
1700 IF G2>J9 THEN 1720
1710 J9=G2
1720 NEXT K1
1730 J9=J9 MAX 2 MIN 32
1740 RETURN
```

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